CLAIMS

What is claimed is:

1. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) determining an airspeed of said vehicle;

b) forming a twist on at least a portion of said wing based at least in part upon said airspeed of said vehicle; and

c) varying said twist based at least in part upon changes in said airspeed of said vehicle.

2. The method of claim 1, further comprising the step of determining a twist distribution to be applied to said at least a portion of said wing.

3. The method of claim 2, wherein said twist distribution is determined by the equation

$$\omega(z) = 1 - \frac{\sqrt{1-(2z/b)^2}}{c(z)/c_{\text{root}}}$$

where $\omega(z)$ is said twist distribution, z is a distance from a root of the wing, b is a wingspan, $c(z)$ is a local wing section chord length, and c_{root} is a root wing section chord length.

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

4. The method of claim 1, further comprising determining a weight of said vehicle.

5. The method of claim 4, further comprising forming said twist on said at least a portion of said wing based at least in part upon said weight of said vehicle.

6. The method of claim 5, further comprising varying said twist based at least in part upon changes in said weight of said vehicle.

7. The method of claim 1, further comprising the step of determining an air density.

8. The method of claim 7, further comprising forming said twist on said at least a portion of said wing based at least in part upon said air density.

9. The method of claim 8, further comprising varying said twist based at least in part upon changes in said air density.

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Fax: (801) 255-5338

10. The method of claim 1, further comprising the step of determining a load factor of said vehicle.

11. The method of claim 10, further comprising forming said twist on said at least a portion of said wing based at least in part upon said load factor of said vehicle.

12. The method of claim 11, further comprising varying said twist based at least in part upon changes in said load factor of said vehicle.

13. The method of claim 1, further comprising the step of determining a wing area of said vehicle.

14. The method of claim 13, further comprising forming said twist on said at least a portion of said wing based at least in part upon said wing area of said vehicle.

15. The method of claim 14, further comprising varying said twist based at least in part upon changes in said wing area of said vehicle.

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Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

16. The method of claim 1, further comprising forming said twist on said at least a portion of said wing in a helical manner.

17. The method of claim 1, further comprising determining a lift coefficient for the wing.

18. The method of claim 17, wherein the lift coefficient is based upon the airspeed of the vehicle, a weight of the vehicle, a load factor, an air density, and a wing area.

19. The method of claim 18, wherein the lift coefficient is calculated by the equation

$$C_L = \frac{W n}{\frac{1}{2}\rho V^2 S}$$

where C_L is the lift coefficient, W is the vehicle weight, n is the load factor, ρ is the air density, V is the airspeed of the vehicle, and S is the wing area.

20. The method of claim 19, wherein said twist is determined by the equation

$$\Omega_{\text{opt}} = \frac{2(1+R_T)C_L}{\pi \widetilde{C}_{L,\alpha}\varepsilon_f}$$

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

where Ω_{OPT} is the twist, R_T is a wing taper ratio, C_L is a lift coefficient, $\tilde{C}_{L,\alpha}$ is an airfoil section lift slope, and ε_f is a local airfoil section flap effectiveness.

21. The method of claim 20, wherein the local airfoil section flap effectiveness ε_f is determined by the equations

$$\varepsilon_f = 1 - \frac{\theta_f - \sin\theta_f}{\pi}$$

and

$$\theta_f = \cos^{-1}(2c_f/c)$$

where c_f is a chord length of a flap and c is an entire chord length.

22. The method of claim 1, wherein said twist is optimized to produce induced drag at substantially the same level as an elliptical wing.

23. The method of claim 1, wherein said at least a portion of said wing comprises an entire cross section of said wing.

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

24. The method of claim 1, wherein said at least a portion of said wing comprises an edge flap on said wing.

25. The method of claim 1, wherein said twist is determined by the equation

$$(\delta_t)_{\text{opt}} = \frac{\kappa_{DL} C_L}{2\kappa_{D\Omega} C_{L,\alpha}}$$

where κ_{DL} is a lift washout contribution to induced drag factor, C_L is a lift coefficient, $\kappa_{D\Omega}$ is a washout contribution to induced drag factor, and $C_{L,\alpha}$ is a wing lift slope.

26. The method of claim 2, wherein said twist distribution is determined by the equation

$$\omega(\theta) = 1 - \frac{\sin(\theta)}{c(\theta)/c_{\text{root}}}$$

where $\omega(\theta)$ is said twist distribution, $c(\theta)$ is a local wing section chord length, c_{root} is a root wing section chord length and

$$\theta = \cos^{-1}(-2z/b)$$

where z is a distance from a root of the wing and b is a wingspan.

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

27. The method of claim 1, wherein said twist is determined by the equation

$$(\delta_t)_{\text{opt}} = \frac{4C_L}{\pi \widetilde{C}_{L,\alpha} \varepsilon_f}$$

where C_L is a lift coefficient, $\widetilde{C}_{L,\alpha}$ is an airfoil section lift slope, and ε_f is an airfoil section flap effectiveness.

28. The method of claim 1, wherein said twist is determined by the equation

$$(\delta_t)_{\text{opt}} = \frac{2(1+R_T)C_L}{\pi \widetilde{C}_{L,\alpha}}$$

where C_L is a lift coefficient, R_T is a wing taper ratio, $c_{\text{tip}}/c_{\text{root}}$, c_{tip} is a wingtip section chord length, c_{root} is a wingroot section chord length, and $\widetilde{C}_{L,\alpha}$ is a airfoil section lift slope.

29. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) determining a weight of said vehicle;

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

b) forming a twist on at least a portion of said wing based at least in part upon said weight of said vehicle; and

c) varying said twist based at least in part upon changes in said weight of said vehicle.

30. The method of claim 29, further comprising the step of determining a twist distribution to be applied to said at least a portion of said wing.

31. The method of claim 29, further comprising determining an airspeed of said vehicle.

32. The method of claim 31, further comprising forming said twist on said at least a portion of said wing based at least in part upon said airspeed of said vehicle.

33. The method of claim 32, further comprising varying said twist based at least in part upon changes in said airspeed of said vehicle.

34. The method of claim 29, further comprising forming said twist on said at least a portion of said wing in a helical manner.

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Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

35. The method of claim 29, further comprising determining a lift coefficient for the wing, said lift coefficient being based upon an airspeed of the vehicle, the weight of the vehicle, a load factor, an air density, and a wing area.

36. The method of claim 29, wherein said at least a portion of said wing comprises an entire cross section of said wing.

37. The method of claim 29, wherein said at least a portion of said wing comprises an edge flap on said wing.

38. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) determining an air density;

b) forming a twist on at least a portion of said wing based at least in part upon said air density; and

c) varying said twist based at least in part upon changes in said air density.

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Phone: (801) 255-5335
Fax: (801) 255-5338

39. The method of claim 38, further comprising the step of determining a twist distribution to be applied to said at least a portion of said wing.

40. The method of claim 38, further comprising determining an airspeed of said vehicle.

41. The method of claim 40, further comprising forming said twist on said at least a portion of said wing based at least in part upon said airspeed of said vehicle.

42. The method of claim 41, further comprising varying said twist based at least in part upon changes in said airspeed of said vehicle.

43. The method of claim 38, further comprising forming said twist on said at least a portion of said wing in a helical manner.

44. The method of claim 38, further comprising determining a lift coefficient for the wing, said lift coefficient being based upon an airspeed of the vehicle, a

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

weight of the vehicle, a load factor, the air density, and a wing area.

45. The method of claim 38, wherein said at least a portion of said wing comprises an entire cross section of said wing.

46. The method of claim 38, wherein said at least a portion of said wing comprises an edge flap on said wing.

47. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) determining a load factor of said vehicle;

b) forming a twist on at least a portion of said wing based at least in part upon said load factor of said vehicle; and

c) varying said twist based at least in part upon changes in said load factor of said vehicle.

48. The method of claim 47, further comprising the step of determining a twist distribution to be applied to said at least a portion of said wing.

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
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49. The method of claim 47, further comprising determining an airspeed of said vehicle.

50. The method of claim 49, further comprising forming said twist on said at least a portion of said wing based at least in part upon said airspeed of said vehicle.

51. The method of claim 50, further comprising varying said twist based at least in part upon changes in said airspeed of said vehicle.

52. The method of claim 47, further comprising forming said twist on said at least a portion of said wing in a helical manner.

53. The method of claim 47, further comprising determining a lift coefficient for the wing, said lift coefficient being based upon an airspeed of the vehicle, a weight of the vehicle, the load factor, an air density, and a wing area.

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Fax: (801) 255-5338

54. The method of claim 47, wherein said at least a portion of said wing comprises an entire cross section of said wing.

55. The method of claim 47, wherein said at least a portion of said wing comprises an edge flap on said wing.

56. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) determining a wing area of said vehicle;

b) forming a twist on at least a portion of said wing based at least in part upon said wing area of said vehicle; and

c) varying said twist based at least in part upon changes in said wing area of said vehicle.

57. The method of claim 56, further comprising the step of determining a twist distribution to be applied to said at least a portion of said wing.

58. The method of claim 56, further comprising determining an airspeed of said vehicle.

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Fax: (801) 255-5338

59. The method of claim 58, further comprising forming said twist on said at least a portion of said wing based at least in part upon said airspeed of said vehicle.

60. The method of claim 59, further comprising varying said twist based at least in part upon changes in said airspeed of said vehicle.

61. The method of claim 56, further comprising forming said twist on said at least a portion of said wing in a helical manner.

62. The method of claim 56, further comprising determining a lift coefficient for the wing, said lift coefficient being based upon an airspeed of the vehicle, a weight of the vehicle, a load factor, an air density, and the wing area.

63. The method of claim 56, wherein said at least a portion of said wing comprises an entire cross section of said wing.

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Fax: (801) 255-5338

64. The method of claim 56, wherein said at least a portion of said wing comprises an edge flap on said wing.

65. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) determining a twist required for reduced induced drag based on operating conditions of said vehicle;

b) forming said twist on at least a portion of said wing; and

c) varying said twist based on changes in said operating conditions.

66. The method of claim 65, further comprising the step of determining a twist distribution to be applied to said at least a portion of said wing.

67. The method of claim 65, further comprising determining an airspeed of said vehicle.

68. The method of claim 67, further comprising forming said twist on said at least a portion of said wing based at least in part upon said airspeed of said vehicle.

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69. The method of claim 68, further comprising varying said twist based at least in part upon changes in said airspeed of said vehicle.

70. The method of claim 65, further comprising forming said twist on said at least a portion of said wing in a helical manner.

71. The method of claim 65, further comprising determining a lift coefficient for the wing, said lift coefficient being based upon an airspeed of the vehicle, a weight of the vehicle, a load factor, an air density, and a wing area.

72. The method of claim 65, wherein said at least a portion of said wing comprises an entire cross section of said wing.

73. The method of claim 65, wherein said at least a portion of said wing comprises an edge flap on said wing.

74. The method of claim 65, further comprising:

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P.O. Box 1909
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Phone: (801) 255-5335
Fax: (801) 255-5338

d) determining a twist distribution to be applied to said at least a portion of said wing, said twist distribution being determined by the equation

$$\omega(y) = 1 - \frac{\sqrt{1-(2y/b)^2}}{c(y)/c_{\text{root}}}$$

where ω(z) is said twist distribution, z is a distance from a root of the wing, b is a wingspan, c is a local wing section chord length, and c_{root} is a root wing section chord length;

wherein step a further comprises determining an airspeed of said vehicle, determining a weight of said vehicle, determining an air density, determining a load factor of said vehicle, and determining a wing area of said vehicle,

wherein a lift coefficient is calculated by the equation

$$C_L = \frac{Wn}{\frac{1}{2}\rho V^2 S_w}$$

where C_L is the lift coefficient, W is the vehicle weight, n is the load factor, ρ is the air density, V is the airspeed of the vehicle, and S_W is the wing area;

wherein the twist is determined by the equation

$$\Omega_{\text{opt}} = \frac{2(1+R_T)C_L}{\pi \widetilde{C}_{L,\alpha}\varepsilon_f}$$

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P.O. Box 1909
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Phone: (801) 255-5335
Fax: (801) 255-5338

where Ω_{OPT} is the twist, R_T is a wing taper ratio, C_L is the lift coefficient, $\tilde{C}_{L,\alpha}$ is an airfoil section lift slope, and ε_f is a local airfoil section flap effectiveness;

wherein the local airfoil section flap effectiveness ε_f is determined by the equations

$$\varepsilon_f = 1 - \frac{\theta_f - \sin\theta_f}{\pi}$$

and

$$\theta_f = \cos^{-1}(2c_f/c)$$

where c_f is a chord length of a flap and c is an entire chord length.

75. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) providing said wing with a twistable portion, said twistable portion being twistable in a helical manner; and

c) twisting said twistable portion to said configuration.

76. The method of claim 75, further comprising the step of determining a twist distribution to be applied to said

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

twistable portion, and undertaking step (c) responsive to said twist distribution.

77. The method of claim 75, further comprising determining an airspeed of said vehicle.

78. The method of claim 77, wherein the step of twisting said twistable portion is based at least in part upon said airspeed of said vehicle.

79. The method of claim 78, wherein said configuration varies based at least in part upon changes in said airspeed of said vehicle.

80. The method of claim 75, further comprising determining said configuration based upon an airspeed of the vehicle, a weight of the vehicle, a load factor, an air density, and a wing area.

81. The method of claim 75, wherein said twistable portion comprises an entire cross section of said wing.

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Phone: (801) 255-5335
Fax: (801) 255-5338

82. The method of claim 75, wherein said twistable portion comprises an edge flap on said wing.

83. A vehicle comprising:

a wing comprising a twistable portion; and

a control system for adjusting the twistable portion;

wherein the twistable portion is adjusted by the control system in response to operating conditions to thereby reduce induced drag.

84. The vehicle of claim 83, wherein the twistable portion is a trailing edge flap on said wing.

85. The vehicle of claim 83, wherein the twistable portion comprises an entire cross section of said wing.

86. The vehicle of claim 83, wherein said twistable portion is configured to twist in a helical manner.

87. The vehicle of claim 83, further comprising at least one sensor for monitoring operating conditions.

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Phone: (801) 255-5335
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88. The vehicle of claim 87, further comprising a computer for receiving data from the at least one sensor and for calculating a twist amount based upon said data.

89. The vehicle of claim 83, wherein the control system comprises a push rod.

90. The vehicle of claim 83, wherein the wing has a variable area.

91. The vehicle of claim 83, wherein the wing has a rectangular planform.

92. The vehicle of claim 83, wherein the wing has a tapered planform.

93. A system for reducing induced drag on a vehicle, said system comprising:

at least one sensor for monitoring operating conditions;

a computer for receiving data from the at least one sensor and for calculating a twist amount based upon said data; and

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

a control system for applying the twist amount on at least a portion of a wing to thereby reduce induced drag.

94. The system of claim 93, wherein the at least one sensor is configured to determine an airspeed of the vehicle.

95. The system of claim 93, wherein the at least one sensor is configured to determine a weight of the vehicle.

96. The system of claim 93, wherein the at least one sensor is configured to determine an air density.

97. The system of claim 93, wherein the at least one sensor is configured to determine a load factor.

98. The system of claim 93, wherein the at least one sensor is configured to determine a wing area.

99. The system of claim 93, wherein the control system comprises a rod for applying the twist to the at least a portion of the wing.

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Phone: (801) 255-5335
Fax: (801) 255-5338

100. The system of claim 99, further comprising a motor for driving the rod.

101. The system of claim 99, further comprising a cogwheel for driving the rod.

102. The system of claim 99, further comprising a hydraulic actuator for driving the rod.

103. The system of claim 99, further comprising a mechanical screw actuator for driving the rod.

104. The system of claim 99, further comprising a rotating shaft having a cam for driving the rod.

105. The system of claim 99, wherein the rod is spring biased to contact the cam.

106. The system of claim 105, wherein the rod is connected to a groove on the cam to thereby produce both a push and a pull on the rod.

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Phone: (801) 255-5335
Fax: (801) 255-5338

107. The system of claim 93, wherein the control system comprises a rotating shaft for applying the twist to the at least a portion of the wing.

108. The system of claim 93, wherein the control system comprises a plurality of rotating shafts for applying the twist to the at least a portion of the wing.

109. The system of claim 93, wherein the control system comprises at least one motor for supplying a rotational force to apply the twist to the at least a portion of the wing.

110. A system for reducing induced drag on a vehicle, said system comprising:

means for determining an amount of twist to be applied to at least a portion of a wing for the purpose of reducing induced drag; and

means for applying a twist to said at least a portion of said wing.

111. The system of claim 110, wherein the means for determining an amount of twist to be applied comprises at least one sensor.

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Phone: (801) 255-5335
Fax: (801) 255-5338

112. The system of claim 111, wherein the at least one sensor is configured to determine at least one of the group consisting of an airspeed of the vehicle, a weight of the vehicle, an air density, a load factor, and a wing area.

113. The system of claim 110, wherein the means for determining an amount of twist to be applied comprises a computer for receiving data and calculating said twist amount.

114. The system of claim 110, wherein the means for applying a twist comprises a rod.

115. The system of claim 114, wherein the means for applying a twist includes at least one of the group consisting of a cogwheel, a hydraulic actuator, a mechanical screw actuator, and a rotating shaft.

116. The system of claim 110, wherein the means for applying a twist comprises at least one motor for supplying a rotational force.

117. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

a) determining a twist distribution to be applied to said wing for the purpose of reducing induced drag;

b) varying a twist on at least a portion of said wing in accordance with said twist distribution while said vehicle is in operation.

118. The method of claim 117, wherein said twist distribution is determined by the equation

$$\omega(y) = 1 - \frac{\sqrt{1-(2y/b)^2}}{c(y)/c_{\text{root}}}$$

where ω(z) is said twist distribution, z is a distance from a root of the wing, b is a wingspan, c is a local wing section chord length, and c_{root} is a root wing section chord length.

119. The method of claim 117, further comprising determining an airspeed of said vehicle.

120. The method of claim 119, further comprising forming said twist on said at least a portion of said wing based at least in part upon said airspeed of said vehicle.

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Phone: (801) 255-5335
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121. The method of claim 120, further comprising varying said twist based at least in part upon changes in said airspeed of said vehicle.

122. The method of claim 117, further comprisingforming said twist on said at least a portion of said wing in a helical manner.

123. The method of claim 117, further comprising determining a lift coefficient for the wing, said lift coefficient being based upon an airspeed of the vehicle, the weight of the vehicle, a load factor, an air density, and a wing area.

124. The method of claim 117, wherein said at least a portion of said wing comprises an entire cross section of said wing.

125. The method of claim 117, wherein said at least a portion of said wing comprises an edge flap on said wing.

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Phone: (801) 255-5335
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126. The method of claim 117, wherein the twist on the at least a portion of the wing is configured to correspond to the twist distribution.

127. The method of claim 117, wherein the twist on the at least a portion of the wing is configured to correspond to a portion of the twist distribution.

128. A method for reducing induced drag on a wing of a vehicle, said method comprising the steps of:

a) determining an airspeed of said vehicle;

b) changing a camber of a portion of said wing based at least in part upon said airspeed of said vehicle; and

c) varying said camber based at least in part upon changes in said airspeed of said vehicle.

129. The method of claim 128, further comprising the step of determining a twist distribution to be applied to said at least a portion of said wing.

130. The method of claim 129, wherein said twist distribution is determined by the equation

$$\omega(z) = 1 - \frac{\sqrt{1-(2z/b)^2}}{c(z)/c_{\text{root}}}$$

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P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

where $\omega(z)$ is said twist distribution, z is a distance from a root of the wing, b is a wingspan, $c(z)$ is a local wing section chord length, and c_{root} is a root wing section chord length.

131. The method of claim 128, further comprising determining a weight of said vehicle.

132. The method of claim 131, further comprising changing said camber of said at least a portion of said wing based at least in part upon said weight of said vehicle.

133. The method of claim 132, further comprising changing said camber of said at least in part upon changes in said weight of said vehicle.

134. The method of claim 128, further comprising the step of determining an air density.

135. The method of claim 134, further comprising changing said camber of said at least a portion of said wing based at least in part upon said air density.

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P.O. Box 1909
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Phone: (801) 255-5335
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136. The method of claim 135, further comprising changing said camber of said at least in part upon changes in said air density.

137. The method of claim 128, further comprising the step of determining a load factor of said vehicle.

138. The method of claim 137, further comprising changing said camber of said at least a portion of said wing based at least in part upon said load factor of said vehicle.

139. The method of claim 138, further comprising changing said camber of said at least in part upon changes in said load factor of said vehicle.

140. The method of claim 128, further comprising the step of determining a wing area of said vehicle.

141. The method of claim 140, further comprising changing said camber of said at least a portion of said wing based at least in part upon said wing area of said vehicle.

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Sandy, Utah 84091-1909
Phone: (801) 255-5335
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142. The method of claim 141, further comprising changing said camber of said at least a portion of said wing based at least in part upon changes in said wing area of said vehicle.

143. The method of claim 128, further comprising determining a lift coefficient for the wing.

144. The method of claim 143, wherein the lift coefficient is based upon the airspeed of the vehicle, a weight of the vehicle, a load factor, an air density, and a wing area.

145. The method of claim 144, wherein the lift coefficient is calculated by the equation

$$C_L = \frac{W n}{\frac{1}{2}\rho V^2 S}$$

where C_L is the lift coefficient, W is the vehicle weight, n is the load factor, ρ is the air density, V is the airspeed of the vehicle, and S is the wing area.

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Phone: (801) 255-5335
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146. The method of claim 145, wherein said twist is determined by the equation

$$\Omega_{\text{opt}} = \frac{2(1+R_T)C_L}{\pi \widetilde{C}_{L,\alpha}\varepsilon_f}$$

where Ω_{OPT} is the twist, R_T is a wing taper ratio, C_L is a lift coefficient, $\widetilde{C}_{L,\alpha}$ is an airfoil section lift slope, and ε_f is a local airfoil section flap effectiveness.

147. The method of claim 146, wherein the local airfoil section flap effectiveness ε_f is determined by the equations

$$\varepsilon_f = 1 - \frac{\theta_f - \sin\theta_f}{\pi}$$

and

$$\theta_f = \cos^{-1}(2c_f/c)$$

where c_f is a chord length of a flap and c is an entire chord length.

148. The method of claim 128, wherein the changing of the camber is optimized to produce induced drag at substantially the same level as an elliptical wing.

Clayton, Howarth & Cannon, P.C.
P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

149. The method of claim 128, wherein said at least a portion of said wing comprises an entire cross section of said wing.

150. The method of claim 128, wherein said at least a portion of said wing comprises an edge flap on said wing.

151. The method of claim 128, wherein said twist is determined by the equation

$$(\delta_t)_{\text{opt}} = \frac{\kappa_{DL} C_L}{2\kappa_{D\Omega} C_{L,\alpha}}$$

where κ_{DL} is a lift washout contribution to induced drag factor, C_L is a lift coefficient, $\kappa_{D\Omega}$ is a washout contribution to induced drag factor, and $C_{L,\alpha}$ is a wing lift slope.

152. The method of claim 129, wherein said twist distribution is determined by the equation

$$\omega(\theta) = 1 - \frac{\sin(\theta)}{c(\theta)/c_{\text{root}}}$$

Clayton, Howarth & Cannon, P.C.
P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

where $\omega(\theta)$ is said twist distribution, $c(\theta)$ is a local wing section chord length, c_{root} is a root wing section chord length and

$$\theta = \cos^{-1}(-2z/b)$$

where z is a distance from a root of the wing and b is a wingspan.

153. The method of claim 128, wherein said twist is determined by the equation

$$(\delta_t)_{\text{opt}} = \frac{4C_L}{\pi \widetilde{C}_{L,\alpha} \varepsilon_f}$$

where C_L is a lift coefficient, $\widetilde{C}_{L,\alpha}$ is an airfoil section lift slope, and ε_f is an airfoil section flap effectiveness.

154. The method of claim 128, wherein said twist is determined by the equation

$$(\delta_t)_{\text{opt}} = \frac{2(1+R_T)C_L}{\pi \widetilde{C}_{L,\alpha}}$$

Clayton, Howarth & Cannon, P.C.
P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338

where C_L is a lift coefficient, R_T is a wing taper ratio, c_{tip}/c_{root}, c_{tip} is a wingtip section chord length, c_{root} is a wingroot section chord length, and $\tilde{C}_{L,\alpha}$ is a airfoil section lift slope.

Clayton, Howarth & Cannon, P.C.
P.O. Box 1909
Sandy, Utah 84091-1909
Phone: (801) 255-5335
Fax: (801) 255-5338